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3.	**Full name, address and postcode of the or of each applicant** *(underline all surnames)*	Quadrise Limited 'Lindean' Rickmansworth Lane Chalfont St. Peter Buckinghamshire SL9 0LX
	Patents ADP number *(if you know it)*	07539372001
	If the applicant is a corporate body, give country/state of incorporation	United Kingdom
4.	**Title of the invention**	Electrical Energy Storage
5.	**Name of your agent** *(if you have one)*	Frank B. Dehn & Co.
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	179 Queen Victoria Street London EC4V 4EL
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Dr. A.R. Beacham
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Electrical Energy Storage

This invention relates to the storage of electrical energy, in particular to systems and methods for storing electrical energy in the form of chemical bonds, more particularly chemical bonds formed by reaction of hydrogen and carbon dioxide.

The rate of generation of electricity cannot always readily be matched with demand. For example, if electricity is generated using solar energy, maximum electricity generation occurs on warm sunny days whereas maximum electricity demand occurs when it is dark and/or cold. Similar problems are encountered with other forms of electricity generation, in particular other forms of generation such as wind or wave power where the rate of production of electricity can vary unpredictably. Even with conventional power stations which feed electricity into the national grid, electricity demand is much higher during the day than during the night. In an attempt to overcome these problems, various methods have been used for the storage of electricity.

Electrical energy can be stored in electrochemical batteries which store electrical energy in the form of chemical energy. Alternatively, electricity can be used, for example, to electrolyse water to produce hydrogen and oxygen and then the hydrogen can be stored in some way until demand for electricity rises. The stored hydrogen is then used to generate electricity to meet the increased demand. For example, the hydrogen can be stored in a pressurised vessel or adsorbed in a metal hydride hydrogen gas adsorption storage system and later released for use in a hydrogen fuel cell to generate electricity (see for example JP 9050820 and JP

8064220). Alternatively, it has been proposed to use hydrogen generated from the electrolysis of water to chemically reduce toluene to form methylcyclohexane (Th. H. Schucan et al, Seasonal Storage of Electricity with Chemically Bound Hydrogen, Electrical Energy Storage Systems Applications Technologies Conference, Chester, UK, 16-18 June 1998). The methylcyclohexane is then stored until demand for electricity increases. Dehydrogenation of the methylcyclohexane then releases hydrogen which can be used in fuel cells for the generation of electricity.

However, the known systems for storing electricity are expensive and inflexible and do not readily lend themselves to storing varying amounts of electrical energy over time. Thus, if batteries are to be used, a large number of batteries must be provided permanently to take into account the maximum possible electrical energy which may need to be stored. Batteries also suffer from the disadvantages that they are both heavy and expensive. Similarly, hydrogen gas adsorption storage systems are inflexible and require large amounts of the adsorbing material to be ready in order to take into account the maximum possible electrical energy which may need to be stored. In addition, there are safety risks associated with the storage of hydrogen gas due to its potentially explosive nature. Similarly, the toluene-methylcyclohexane system requires the preliminary storage of large amounts of toluene, which is both toxic and flammable, in readiness for use to store electrical energy.

There is therefore still a need for a system and methods for storing electrical energy which are flexible, environmentally friendly and easily adaptable to widely differing rates of electricity generation.

According to one aspect of the present invention, there is therefore provided a system for the storage of electrical energy, said system comprising electrolysis means connectable to supplies of water and electricity and operable to provide the electrolysis of water to generate hydrogen, reaction means for receiving hydrogen generated by said electrolysis means, the reaction means providing the reaction of said hydrogen with carbon dioxide to form a storage compound, means for the supply of carbon dioxide to said reaction means, and storage means connected to said reaction means for the storage of said storage compound. As discussed below, the system preferably further comprises regeneration means for the generation of electrical energy either directly or indirectly from the storage compound.

As used herein, a storage compound is any compound that may be produced via the reaction of hydrogen and carbon dioxide, for example an organic compound such as methanol or a higher alcohol, preferably methanol, or a C_{1-8}-aldehyde, C_{1-8}-ether or C_{1-8}-hydrocarbon, preferably a C_{1-4}-aldehyde, C_{1-4}-ether or C_{1-4}-hydrocarbon, more preferably a C_1-aldehyde, C_1-ether or C_1-hydrocarbon. Methanol is an especially preferred storage compound. The storage compound may be a gas, liquid or solid under standard conditions of temperature and pressure. For ease of transfer and storage, the storage compound is preferably a liquid under standard conditions.

The electricity supply may be of any form, for example the mains grid. The system may itself further comprise electricity generating means, whereby electricity may be generated and supplied to the electrolysis means. Such electricity generating means may be any conventional generating means. Examples of suitable generating means include solar panels, wind-powered generators and wave-powered generators.

These are particularly suitable for use in the invention. Solar panels are preferred generating means.

The water supply means may be any source of water connectable to the system, for example the mains water supply connected via a suitable deioniser. Alternatively, a tank of de-ionised water may be provided for connection to the system. In a domestic setting, the water supply may suitably be water from the household supply which has been de-ionised using conventional methodology. Commercially available water electrolysis units often comprise a suitable deioniser so that they may use mains water.

Suitable electrolysis means for the electrolysis of water are known in the art. Suitable equipment is commercially available for example from the company Teledyne Brown Engineering of Maryland, U.S.A..

The reaction means may be any means suitable for the reaction of hydrogen with carbon dioxide to form a storage compound. Suitable means are known in the art. The means optionally comprise a catalyst, and are optionally supplied with heating and pressurizing means. Catalysts and conditions for the reaction of hydrogen with carbon dioxide to form suitable storage compounds are well known in the art (see for example The Catalyst Handbook, 2nd Ed., Ed. M.V. Twigg, Oxford University Press, 1997; GB 1 595 413).

The hydrogen produced in the electrolysis means may be fed directly to the reaction means. Alternatively, the system may optionally comprise means, for example a pressurised cylinder or tank, for the temporary storage of hydrogen before it is fed into the reaction means.

The carbon dioxide supply means may comprise means

for the extraction of carbon dioxide from the air. Such extraction means are known in the art (Y. Hirayama et al, Proceedings of the Second International Conference on Carbon Dioxide Removal (ICCDR-2), 435-438, 419-422 (1995) and Polymeric Gas Separation Membranes by Robert E. Kesting, Ed. A.K. Fritzsche, John Wiley & Sons (1993)). Alternatively or additionally, the carbon dioxide supply means may comprise means for attachment to a store of carbon dioxide which may be stored in gaseous, liquid or solid form.

The carbon dioxide supply means may alternatively comprise means for the extraction of carbon dioxide from power station flue gases or other industrial exhaust gases using known methodology (see for example Carbon Dioxide Removal from Coal Fired Power Plants (Energy and Environment Vol 1) by Chris Hendriks, Kluwer Academic Publications (1994)). Typically, carbon dioxide may comprise 20-25% of such flue gases.

The storage means may be any means suitable for the storage of the storage compound, for example tanks, drums or the like. The storage means may be any suitable size taking into account the maximum amount of electrical energy it is desired to store at any one stage. For example, a system for domestic use may involve a storage means of sufficient size to merely store excess electrical energy produced from a solar panel during the course of a day for generation of electricity during the night. The storage means may be at some distance from the reaction means and the system may further comprise one or more pumps or other suitable means for the transfer of the storage compound from the reaction means to the storage means. For example, in a domestic system, the storage means may comprise a tank buried in the garden of the house, whilst the electrolysis and reaction means may be located inside

the house or garage.

A preferred embodiment of the system further comprises regeneration means for the generation of electrical energy either directly or indirectly from the storage compound. If necessary, a pump or other suitable means may be provided to transfer the storage compound from the storage means to the regeneration means. The regeneration means may comprise a suitable fuel cell for the conversion of the storage compound directly to electrical energy. For example, US 4524113 discloses a methanol fuel cell. Methanol fuel cells may be used if the storage compound is methanol. If oxygen is required for the functioning of the fuel cell, it may be in the form of oxygen from the air. If carbon dioxide is produced as a by-product from the fuel cell it may be recycled to the reaction means for reaction with further hydrogen. In such circumstances, the carbon dioxide supply means may comprise means for the recycling of carbon dioxide from the fuel cell.

Alternatively, the regeneration means may comprise further reaction means whereby the storage compound may be converted back into hydrogen and carbon dioxide, together with a hydrogen fuel cell for the conversion of the hydrogen into electricity (see for example GB 1165679). Suitable fuel cells are known in the art, for example those available commercially from Ballard Power Systems Inc. of British Columbia, Canada. The carbon dioxide so produced may be recycled for reaction with further hydrogen. In such circumstances, the carbon dioxide supply means may comprise means for the recycling of carbon dioxide from the regeneration means.

The electricity generated from the storage means may be used to meet domestic or commercial demand. Alternatively, the regeneration means could comprise

part of a vehicle and the electricity could be used to power the vehicle.

Preferably, the system is fully automated and its operation is controlled by a suitable control system, for example a microprocessor and the necessary circuitry.

The invention extends to a method for the storage of electrical energy utilising carbon dioxide and water, the method comprising the following steps:

(a) electrolysis of water to yield hydrogen;
(b) reaction of the hydrogen from step (a) with carbon dioxide to form at least one storage compound;
(c) storage of said storage compound; and
(d) subsequent use of said storage compound to generate electricity either directly or indirectly.

The method and system of the invention utilise readily available compounds, namely water and carbon dioxide, in the storage of electricity. Both compounds are cheap, readily available, and pose no particular storage problems. Electrical energy is stored in the form of chemical energy in the bonds of a suitable storage compound formed by the reaction of hydrogen with carbon dioxide.

The electrolysis of water may be carried out using conventional electrolysis technology. The electrolysis of water produces hydrogen which is retained for further reaction and oxygen which may be released to the air. Preferably, the efficiency of the electrolysis step is about 80% or greater.

The hydrogen generated from the electrolysis step is then reacted with carbon dioxide to form a storage

compound as hereinbefore defined. The storage compound may be a gas, liquid or solid under standard conditions of temperature and pressure. For ease of transfer and storage, the storage compound is preferably a liquid under standard conditions.

Catalysts and conditions for the reaction of hydrogen with carbon dioxide to form suitable storage compounds are well known in the art (see for example The Catalyst Handbook, 2nd Ed., Ed. M.V. Twigg, Oxford University Press, 1997; GB 1 595 413). For example, for the reaction of hydrogen and carbon dioxide to produce methanol, a temperature range of about 210-240°C and a pressure of about 50-100 bar are suitable. The catalyst may be a conventional zinc oxide/copper/alumina catalyst, for example a catalyst comprising approximately 60% by weight copper, 30% by weight zinc oxide and 10% by weight alumina. Suitable catalysts include those available commercially from ICI under the trade name "51 Series".

The carbon dioxide used in step (b) may be extracted from the air as required using known methodology. Alternatively or additionally, carbon dioxide may be stored in gaseous, liquid or solid form, ready for reaction as required. The major side product of the reaction of carbon dioxide and hydrogen is water, which may be safely released to the environment.

The storage compound may be purified if necessary, for example by purging of unreacted hydrogen and carbon dioxide. Such purged gases may then be recycled for further use in step (b) of the method of the invention.

Electrical energy is stored in the form of chemical energy in the bonds of the storage compound. The storage compound may be stored, for example in a storage

tank, until there is a need for electricity to be regenerated by releasing the energy stored in said chemical bonds. The period of storage will depend on the circumstances but may vary from a few hours to weeks or months. The storage means may be any means suitable for the storage of such compounds, for example tanks, drums or the like. The storage means may be any suitable size taking into account the maximum amount of electrical energy it is desired to store at any one time. For example, a system for domestic use may involve a storage means of sufficient size to merely store excess electrical energy produced from a solar panel during the course of a day for generation of electricity during the day. Alternatively, it may be desired to store energy produced from solar panels (or any other source of electricity) during the summer for use in the winter, in which case larger storage means are required. The method of the invention therefore provides a flexible method for the storage of electrical energy.

When demand for electrical energy increases, the energy stored in the chemical bonds of the storage compound may be released and used to generate electricity either directly or indirectly. For example, with suitable catalysts the storage compound may be converted back into carbon dioxide and hydrogen in a reverse of the original formation reaction and the hydrogen then used in a fuel cell to generate electricity. The hydrogen may need to be further processed to ensure that it does not contain quantities of carbon dioxide or carbon monoxide which may interfere with the functioning of the fuel cell. These gases may be removed using the processes disclosed in M. Iwase and S. Kawatsu, Proceedings of the 29th International Symposium on Automotive Technology and Automation: Electric, Hydrid and Alternative Fuel Vehicles, p 295,

June 1996, and Initial Conceptual Design Report, Allison Engine Company for US Dept of Energy DOE/CH/10435-01, February 1994. If oxygen is required for the functioning of the fuel cell, it may be taken from the air.

Alternatively, if suitable fuel cells are available, the storage compound may be used directly in a fuel cell. For example, methanol fuel cells are known in the art (see US 4524113 for an example of a methanol fuel cell). Carbon dioxide may be one of the by-products of a methanol fuel cell.

If the storage compound is converted back into hydrogen and carbon dioxide or if a fuel cell produces carbon dioxide as a by-product, there is an added advantage in that the carbon dioxide so produced may be recycled for reaction with further hydrogen. The carbon dioxide used in step (c) may therefore comprise recycled carbon dioxide. In a preferred embodiment, the carbon dioxide in step (c) comprises recycled carbon dioxide topped up if required by carbon dioxide extracted from the air.

Both hydrogen and methanol fuel cells generate water as a by-product, which may be released to the environment or recycled for use in the electrolysis step to generate further hydrogen.

The electrical energy for use in the electrolysis of water in step (a) may be generated by any conventional generating means. However, the method of the invention is particularly suitable for use in storing electricity produced by renewable energy sources, for example solar energy, wind power or wave power, where the amount of electricity generated is highly unpredictable or varies substantially with the

time of day or the time of year. The method may also be useful for the storage of electricity generated by nuclear or oil, gas or coal fired power stations during periods of low demand, ready for feeding back into the national grid at times of higher demand. Electrical energy generation using renewable energy sources is preferred.

The use of methanol as the storage compound in the methods of the invention is preferred. Methanol may be produced via the reaction of hydrogen with carbon dioxide. Catalyst for this reaction are well known in the art and are commercially available. Fuel cells for the direct conversion of methanol to electricity are also known. Alternatively, methanol may be converted back into hydrogen and carbon dioxide. The hydrogen may be used in a fuel cell whilst the carbon dioxide may be recycled for reaction with further hydrogen to generate further methanol.

According to a further feature of the present invention, there is therefore provided a further method for the storage of electrical energy, said method comprising the following steps:

(a) electrolysis of water to yield hydrogen;
(b) reaction of the hydrogen from step (a) to form methanol;
(c) storage of the methanol; and
(d) subsequent use of the methanol to generate electricity either directly or indirectly.

Again, the electricity used in step (a) may be generated by any conventional generating means. Electrical energy generation using renewable energy sources is preferred.

Methanol is a useful chemical in its own right. Rather than use methanol generated by any of the above methods for conversion into electricity, it may be sold as an industrial feedstock or used as a fuel in for example a vehicle.

According to a further feature of the present invention, there is therefore provided a method for the production of methanol, said method comprising the following steps:

(a) electrolysis of water to yield hydrogen; and
(b) reaction of the hydrogen from step (a) to form methanol.

In step (b), the hydrogen is preferably reacted with carbon dioxide using known methodology. The carbon dioxide may be extracted from the air or from industrial exhaust gases as required using known methodology. Alternatively or additionally, carbon dioxide may stored in gaseous, liquid or solid form, ready for reaction as required. The major side product of the reaction of carbon dioxide and hydrogen is water, which may be safely released to the environment or recycled for use in step (a).

The invention will be further illustrated, by way of example, with reference to the following Drawings:

Figure 1 illustrates in schematic form one embodiment of an electrical energy storage system according to the invention;

Figure 2 illustrates in schematic form the processing steps in an embodiment of the electrical energy storage method of the invention wherein the storage compound is methanol; and

Figure 3 illustrates in schematic form an example of the component layout for an embodiment of an automated electrical energy storage system according to the invention wherein methanol is the storage compound.

Figure 1 illustrates in schematic form one embodiment of an electrical energy storage system according to the invention. Water, for example from the mains supply, is supplied via inlet 1 to a water storage tank 2. The water is deionised in a deioniser 3 of a known type and then supplied to a hydrogen generator 4, also of a known type, comprising a unit for the electrolysis of water. In the hydrogen generator, water is electrolysed to produce oxygen, which is discharged through outlet 5, and hydrogen which is fed through outlet 6 to a dryer 7. After drying, the hydrogen is fed through a compressor 8 to a pressurised hydrogen storage means 9. The hydrogen is reacted with carbon dioxide in a microreactor 10 containing a suitable catalyst to form a storage compound, for example methanol. Pipe 11 carries the storage compound as well as some unreacted hydrogen and carbon dioxide to purification means 12. Purified storage compound is fed through pipe 13 to a suitable storage means (not shown), such as a tank, whilst any unreacted gases are separated by the purification means and are recycled to the reactor 10 via pipe 14.

To generate electricity, storage compound is returned from the storage means via pipe 21 to regeneration means 22. The regeneration means 22 comprises a suitable fuel cell, and optionally a reactor, to convert the storage compound back into carbon dioxide and hydrogen. Fuel cells and reactors suitable for this purpose are known. Carbon dioxide generated by operation of the regeneration means may be recycled via pipe 23 and compressor 8' to a pressurised

storage vessel 20. Carbon dioxide is supplied to the microreactor 10 from pressurised storage vessel 20. In addition to recycled carbon dioxide, the storage vessel 20 is supplied from an initial carbon dioxide store 15 and/or a carbon dioxide/air separation means 17. The separation means 17 may comprise a suitable membrane, plus an air supply inlet 16 and an outlet 19 for carbon dioxide-free air.

Water produced in the regeneration means 22 may be recycled via pipe 24 to the water storage tank 2.

Figure 2 illustrates in schematic form an embodiment of the electrical energy storage method of the invention wherein the storage compound is methanol. Sunlight falling on solar panels is used to generate electricity. The electricity is used to electrolyse water to produce hydrogen and oxygen. The hydrogen is reacted with carbon dioxide to produce methanol. The carbon dioxide may have been recycled, extracted from the air or brought in from outside the system. The methanol may be stored in a tank, and then used as required, either directly in a methanol fuel cell to produce electricity, or dissociated into hydrogen and carbon dioxide, with the hydrogen then used in a hydrogen fuel cell. In either case, electricity is generated and water is a side product. The water may be released to the environment or recycled for use in the electrolysis step if desired.

Figure 3 illustrates in schematic form a component layout for one embodiment of an automated electrical energy storage system according to the invention wherein methanol is the storage compound. The main components of the system are provided in a cabinet which in a domestic system, it is envisaged, might be of similar dimensions to a refrigerator. Electricity supply means

25 supply electrical energy, for example solar energy, to the system. Water is introduced into the system via inlet 1. The electrical energy is used to electrolyse water to produce hydrogen and oxygen, and the oxygen is released to the atmosphere via outlet 5. The hydrogen is reacted with carbon dioxide, introduced via inlet 26, to produce methanol via a series of reaction steps. The methanol may be transferred via inlet and outlet means 13, 21 to and from suitable storage means (not shown) as required. Methanol may be used directly in a methanol fuel cell to produce electricity or dissociated into hydrogen and carbon dioxide and the hydrogen used in a hydrogen fuel cell. Electricity is supplied from the system via line 27.

The invention will be further illustrated by reference to the following non-limiting Examples.

Examples

The Examples illustrate the use of a domestic electrical energy storage system according to the invention which utilizes solar energy to generate electricity with methanol as the storage compound. Three cities, Miami, San Diego and Syracuse are used to illustrate the working of the system with varying amounts of sunlight. It is assumed that solar panels cover the whole of the house roof area in each Example.

Example 1: House in Miami converting solar energy with an efficiency of 17.1%

Miami	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	$kWh/m^2/day$	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.0	130	650	17.1	111.2	25	86.2	8.0	25	6.9	1.2
Feb	5.4	130	702	17.1	120.0	25	95.0	8.9	25	6.9	2.0
Mar	5.6	130	728	17.1	124.5	25	99.5	9.3	25	6.9	2.4
Apr	5.7	130	741	17.1	126.7	25	101.7	9.5	25	6.9	2.6
May	5.0	130	650	17.1	111.2	25	86.2	8.0	25	6.9	1.2
June	4.5	130	585	17.1	100.0	25	75.0	7.0	25	6.9	0.1
July	4.8	130	624	17.1	106.7	25	81.7	7.6	25	6.9	0.8
August	5.0	130	650	17.1	111.2	25	86.2	8.0	25	6.9	1.2
Sept	4.9	130	637	17.1	108.9	25	83.9	7.8	25	6.9	1.0
Oct	5.1	130	663	17.1	113.4	25	88.4	8.2	25	6.9	1.4
Nov	4.9	130	637	17.1	108.9	25	83.9	7.8	25	6.9	1.0
Dec	4.9	130	637	17.1	108.9	25	83.9	7.8	25	6.9	1.0

<u>Notes</u>

1 The Kyocera Corporation of Japan holds the world record for conversion efficiency in a multicrystal photovoltaic cell of 17.1%. Source: Kyocera Advertising Literature.

2 The average house in the USA consumes 18800 kWh energy per annum. This figure has been divided by 365 days and the result split equally between day and night. Source: The North Carolina Solar Centre.

3 Net heat of combustion (formation) of methanol is 19.94 MJ/kg or 7.29 kWh/litre. Source: Technical Data on Fuel, 7th Edition, Eds. Rose and Cooper, The British National Committee World Energy Conference (1977)
Methanol is typically produced with a 68 - 72% efficiency. The lower figure has been used in these calculations.

4 The efficiency of a methanol fuel cell is typically between 50 and 55%. The lower figure has been used in these calculations.

Example 2: House in San Diego converting solar energy with an efficiency of 17.1%

San Diego	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	kWh/m²/day	m²	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.1	130	663	17.1	113.4	25	88.4	8.2	25	6.9	1.4
Feb	5.5	130	715	17.1	122.3	25	97.3	9.1	25	6.9	2.2
Mar	5.7	130	741	17.1	126.7	25	101.7	9.5	25	6.9	2.6
Apr	5.9	130	767	17.1	131.2	25	106.2	9.9	25	6.9	3.0
May	5.2	130	676	17.1	115.6	25	90.6	8.5	25	6.9	1.6
June	5.1	130	663	17.1	113.4	25	88.4	8.2	25	6.9	1.4
July	5.6	130	728	17.1	124.5	25	99.5	9.3	25	6.9	2.4
August	5.9	130	767	17.1	131.2	25	106.2	9.9	25	6.9	3.0
Sept	5.8	130	754	17.1	128.9	25	103.9	9.7	25	6.9	2.8
Oct	5.8	130	754	17.1	128.9	25	103.9	9.7	25	6.9	2.8
Nov	5.4	130	702	17.1	120.0	25	95.0	8.9	25	6.9	2.0
Dec	5.0	130	650	17.1	111.2	25	86.2	8.0	25	6.9	1.2

Notes - as for Example 1

Example 3: House in Syracuse converting solar energy with an efficiency of 17.1%

Syracuse	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	$kWh/m^2/day$	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	2.8	130	364	17.1	62.2	25	37.2	3.5	25	6.9	-3.4
Feb	3.6	130	468	17.1	80.0	25	55.0	5.1	25	6.9	-1.7
Mar	4.2	130	546	17.1	93.4	25	68.4	6.4	25	6.9	-0.5
Apr	4.5	130	586	17.1	100.0	25	75.0	7.0	25	6.9	0.1
May	4.6	130	598	17.1	102.3	25	77.3	7.2	25	6.9	0.3
June	4.7	130	611	17.1	104.5	25	79.5	7.4	25	6.9	0.6
July	4.9	130	637	17.1	108.9	25	83.9	7.8	25	6.9	1.0
August	4.8	130	624	17.1	106.7	25	81.7	7.6	25	6.9	0.8
Sept	4.5	130	585	17.1	100.0	25	75.0	7.0	25	6.9	0.1
Oct	3.7	130	481	17.1	82.3	25	57.3	5.3	25	6.9	-1.5
Nov	2.3	130	299	17.1	51.1	25	26.1	2.4	25	6.9	-4.4
Dec	2.1	130	273	17.1	46.7	25	21.7	2.0	25	6.9	-4.8

Notes - as for Example 1

Example 4: House in Miami converting solar energy with an efficiency of 33%

Miami	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	kWh/m^2/day	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.0	130	650	33	214.5	25	189.5	17.7	25	6.9	10.8
Feb	5.4	130	702	33	231.7	25	206.7	19.3	25	6.9	12.4
Mar	5.6	130	728	33	240.2	25	215.2	20.1	25	6.9	13.2
Apr	5.7	130	741	33	244.5	25	219.5	20.5	25	6.9	13.6
May	5.0	130	650	33	214.5	25	189.5	17.7	25	6.9	10.8
June	4.5	130	585	33	193.1	25	168.1	15.7	25	6.9	8.8
July	4.8	130	624	33	205.9	25	180.9	16.9	25	6.9	10.0
August	5.0	130	650	33	214.5	25	189.5	17.7	25	6.9	10.8
Sept	4.9	130	637	33	210.2	25	185.2	17.3	25	6.9	10.4
Oct	5.1	130	663	33	218.8	25	193.8	18.1	25	6.9	11.2
Nov	4.9	130	637	33	210.2	25	185.2	17.3	25	6.9	10.4
Dec	4.9	130	637	33	210.2	25	185.2	17.3	25	6.9	10.4

Notes

1 The Swiss Federal Institute of Technology has recently announced solar cells based on Titanium Dioxide which have efficiencies as high as 33% (New Scientist, No. 2155, p 11, 10 October 1998)

2-4 as for Example 1

Example 5: House in San Diego converting solar energy with an efficiency of 33%

San Diego	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	$kWh/m^2/day$	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.1	130	663	33	218.8	25	193.8	18.1	25	6.9	11.2
Feb	5.5	130	715	33	236.0	25	211.0	19.7	25	6.9	12.8
Mar	5.7	130	741	33	244.5	25	219.5	20.5	25	6.9	13.6
Apr	5.9	130	767	33	253.1	25	228.1	21.3	25	6.9	14.4
May	5.2	130	676	33	223.1	25	198.1	18.5	25	6.9	11.6
June	5.1	130	663	33	218.8	25	193.8	18.1	25	6.9	11.2
July	5.6	130	728	33	240.2	25	215.2	20.1	25	6.9	13.2
August	5.9	130	767	33	253.1	25	228.1	21.3	25	6.9	14.4
Sept	5.8	130	754	33	248.8	25	223.8	20.9	25	6.9	14.0
Oct	5.8	130	754	33	248.8	25	223.8	20.9	25	6.9	14.0
Nov	5.4	130	702	33	231.7	25	206.7	19.3	25	6.9	12.4
Dec	5.0	130	650	33	214.5	25	189.5	17.7	25	6.9	10.8

Notes

1 The Swiss Federal Institute of Technology has recently announced solar cells based on Titanium Dioxide which have efficiencies as high as 33% (New Scientist, No. 2155, p 11, 10 October 1998)

2-4 as for Example 1

Example 6: House in Syracuse converting solar energy with an efficiency of 33%

Syracuse	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	kWh/m²/day	m²	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	2.8	130	364	33	120.1	25	95.1	8.9	25	6.9	2.0
Feb	3.6	130	468	33	154.4	25	129.4	12.1	25	6.9	5.2
Mar	4.2	130	546	33	180.2	25	155.2	14.5	25	6.9	7.6
Apr	4.5	130	585	33	193.1	25	168.1	15.7	25	6.9	8.8
May	4.6	130	598	33	197.3	25	172.3	16.1	25	6.9	9.2
June	4.7	130	611	33	201.6	25	176.6	16.5	25	6.9	9.6
July	4.9	130	637	33	210.2	25	185.2	17.3	25	6.9	10.4
August	4.8	130	624	33	205.9	25	180.9	16.9	25	6.9	10.0
Sept	4.5	130	585	33	193.1	25	168.1	15.7	25	6.9	8.8
Oct	3.7	130	481	33	158.7	25	133.7	12.5	25	6.9	5.6
Nov	2.3	130	299	33	98.7	25	73.7	6.9	25	6.9	0.0
Dec	2.1	130	273	33	90.1	25	65.1	6.1	25	6.9	-0.8

Notes

1 The Swiss Federal Institute of Technology has recently announced solar cells based on Titanium Dioxide which have efficiencies as high as 33% (New Scientist, No. 2155, p 11, 10 October 1998)

2-4 as for Example 1

Example 7 - Miami Minimum Solar Energy Conversion Efficiency

Miami	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	kWh/m^2/day	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.0	130	650	15	97.5	25	72.5	6.8	25	6.9	-0.1
Feb	5.4	130	702	15	105.3	25	80.3	7.5	25	6.9	0.6
Mar	5.6	130	728	15	109.2	25	84.2	7.9	25	6.9	1.0
Apr	5.7	130	741	15	111.2	25	86.2	8.0	25	6.9	1.2
May	5.0	130	650	15	97.5	25	72.5	6.8	25	6.9	-0.1
June	4.5	130	585	15	87.8	25	62.8	5.9	25	6.9	-1.0
July	4.8	130	624	15	93.6	25	68.6	6.4	25	6.9	-0.5
August	5.0	130	650	15	97.5	25	72.5	6.8	25	6.9	-0.1
Sept	4.9	130	637	15	95.6	25	70.6	6.6	25	6.9	-0.3
Oct	5.1	130	663	15	99.5	25	74.5	6.9	25	6.9	0.1
Nov	4.9	130	637	15	95.6	25	70.6	6.6	25	6.9	-0.3
Dec	4.9	130	637	15	95.6	25	70.6	6.6	25	6.9	-0.3

Average methanol produced 6.9 litres per day
Average methanol consumed 6.9 litres per day

Notes - as for Example 1

Example 8 - San Diego Minimum Solar Energy Conversion Efficiency

San Diego	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	$kWh/m^2/day$	m^2	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	5.1	130	663	14	92.8	25	67.8	6.3	25	6.9	-0.5
Feb	5.5	130	715	14	100.1	25	75.1	7.0	25	6.9	0.1
Mar	5.7	130	741	14	103.7	25	78.7	7.3	25	6.9	0.5
Apr	5.9	130	767	14	107.4	25	82.4	7.7	25	6.9	0.8
May	5.2	130	676	14	94.6	25	69.6	6.5	25	6.9	-0.4
June	5.1	130	663	14	92.8	25	67.8	6.3	25	6.9	-0.5
July	5.6	130	728	14	101.9	25	76.9	7.2	25	6.9	0.3
August	5.9	130	767	14	107.4	25	82.4	7.7	25	6.9	0.8
Sept	5.8	130	754	14	105.6	25	80.6	7.5	25	6.9	0.7
Oct	5.8	130	754	14	105.6	25	80.6	7.5	25	6.9	0.7
Nov	5.4	130	702	14	98.3	25	73.3	6.8	25	6.9	0.0
Dec	5.0	130	650	14	91.0	25	66.0	6.2	25	6.9	-0.7

Average methanol produced 7.0 litres per day
Average methanol consumed 6.9 litres per day

Notes - as for Example 1

Example 9 - Syracuse Minimum Solar Energy Conversion Efficiency

Syracuse	Incident Radiation	House Roof Area	Total Incident Radiation	% efficiency[1] of solar energy conversion to electricity	Electricity Generated	Electricity Consumed During Daylight hours[2]	Electricity available for methanol production	Methanol Produced[3]	Electricity Consumed at night[2]	Methanol Consumed at night[4]	Residual Methanol
	kWh/m²/day	m²	kWh/day		kWh/day	kWh	kWh	litres/day	kWh	litres/day	litres/day
Jan	2.8	130	364	20	72.8	25	47.8	4.5	25	6.9	-2.4
Feb	3.6	130	468	20	93.6	25	68.6	6.4	25	6.9	-0.5
Mar	4.2	130	546	20	109.2	25	84.2	7.9	25	6.9	1.0
Apr	4.5	130	585	20	117.0	25	92.0	8.6	25	6.9	1.7
May	4.6	130	598	20	119.6	25	94.6	8.8	25	6.9	2.0
June	4.7	130	611	20	122.2	25	97.2	9.1	25	6.9	2.2
July	4.9	130	637	20	127.4	25	102.4	9.6	25	6.9	2.7
August	4.8	130	624	20	124.8	25	99.8	9.3	25	6.9	2.5
Sept	4.5	130	585	20	117.0	25	92.0	8.6	25	6.9	1.7
Oct	3.7	130	481	20	96.2	25	71.2	6.6	25	6.9	-0.2
Nov	2.3	130	299	20	59.8	25	34.8	3.2	25	6.9	-3.6
Dec	2.1	130	273	20	54.6	25	29.6	2.8	25	6.9	-4.1

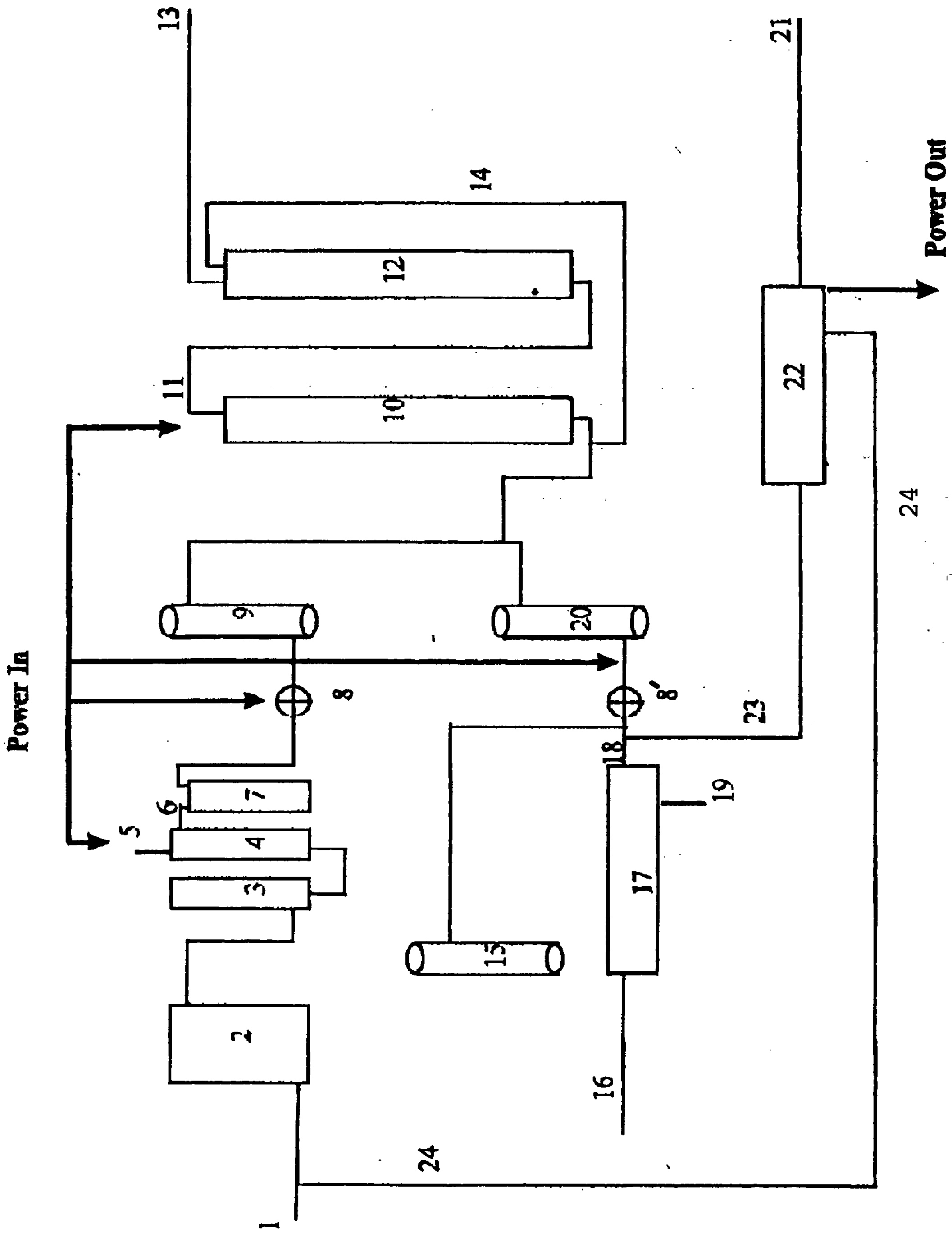
Average methanol produced 7.1 litres per day
Average methanol consumed 6.9 litres per day

Notes - as for Example 1

From the Examples, it can be seen that the more efficiently solar energy is converted to electricity, the more methanol may be produced for a given incidence of solar radiation. For a given efficiency of solar cell, the higher the incidence of solar radiation then the more methanol is produced. In sunny areas such as Miami and San Diego, a minimum solar cell efficiency in the region of 18-20% may be sufficient to satisfy the total demand for power in a typical domestic house. In areas with less sunshine such as Syracuse, a solar cell efficiency of about 26% may be sufficient to satisfy demand. About 1-16 litres of methanol might be produced per day in a typical domestic system according to the invention.

The amount of methanol produced and stored during the day may not be sufficient to meet the full electricity demands of a house during the night. In such situations, the shortfall in electricity may be made up using cheap nighttime electricity from the national grid. Cheap nighttime electricity may also be used to produce further methanol for storage. The methanol may then be used to generate electricity as required, for example during the day when the cost of electricity from the national grid is higher.

In situations where the amount of methanol produced and stored during the day exceeds the amount needed to generate electricity to meet nighttime demand, any excess electricity may be exported to the national grid, or the methanol stored to meet future electricity demand. Alternatively, excess methanol may be used for some other purpose, for example in a methanol fuel cell to power a vehicle.


Power In
Power Out
1
2
3
4
5
6
7
8
8'
9
10
11
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13
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15
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17
18
19
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24

FIG. 1

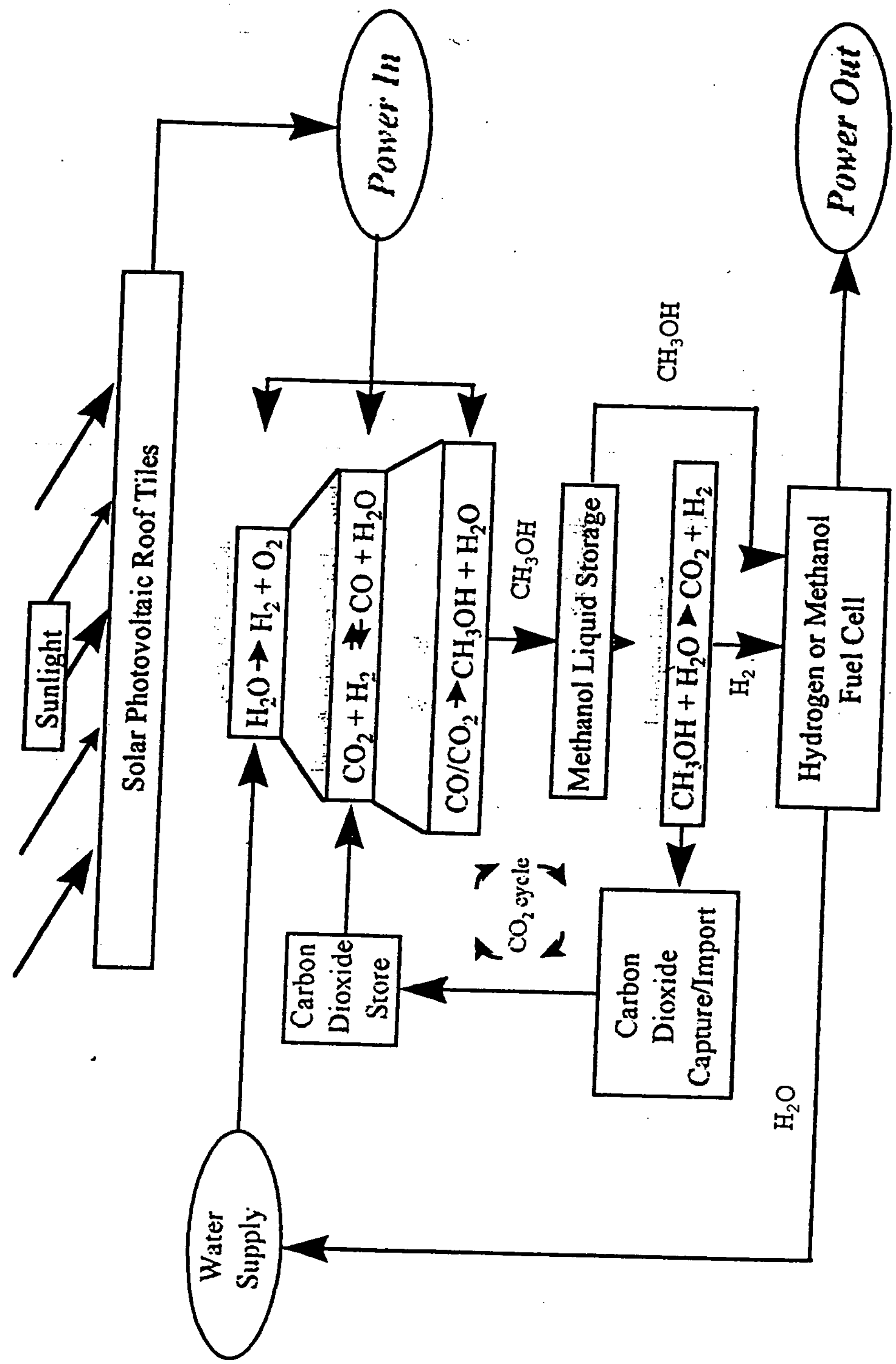
Sunlight
Solar Photovoltaic Roof Tiles
Power In
$H_2O \rightarrow H_2 + O_2$
$CO_2 + H_2 \rightleftharpoons CO + H_2O$
$CO/CO_2 \rightarrow CH_3OH + H_2O$
CH_3OH
Methanol Liquid Storage
CH_3OH
$CH_3OH + H_2O \rightarrow CO_2 + H_2$
H_2
Hydrogen or Methanol Fuel Cell
Power Out
CO_2 cycle
Carbon Dioxide Store
Carbon Dioxide Capture/Import
H_2O
Water Supply

FIG. 2

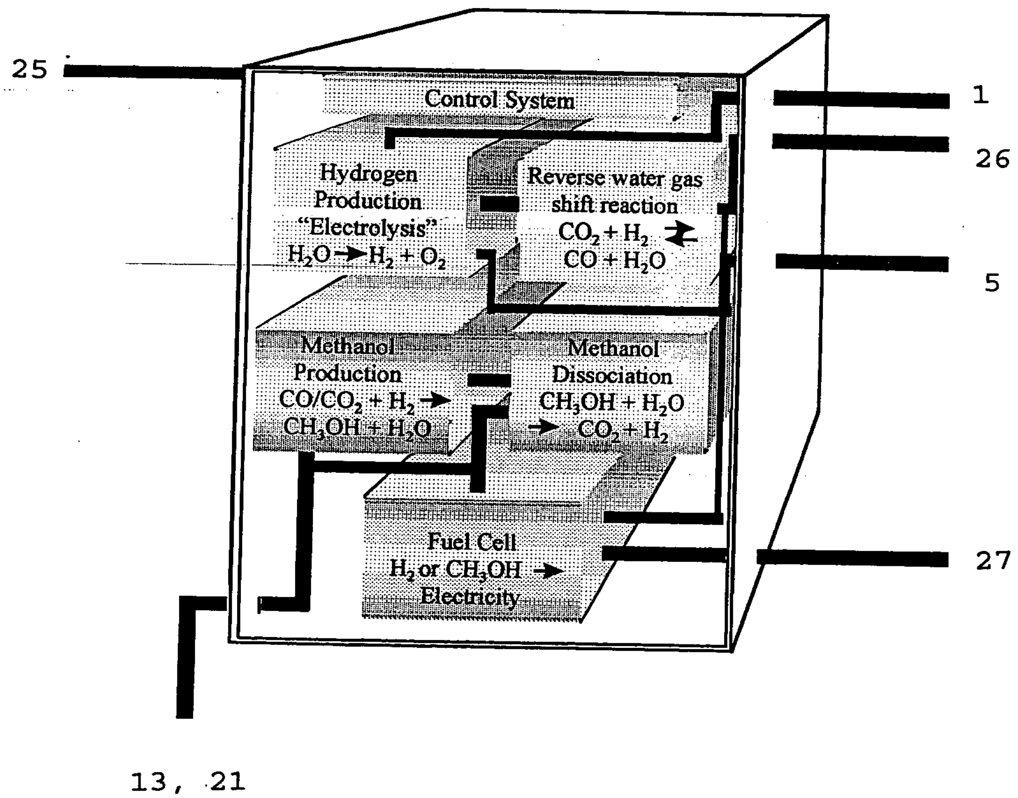
25
Control System
1
26
Hydrogen
Production
"Electrolysis"
$H_2O \rightarrow H_2 + O_2$
Reverse water gas
shift reaction
$CO_2 + H_2 \rightleftarrows$
$CO + H_2O$
5
Methanol
Production
$CO/CO_2 + H_2 \rightarrow$
$CH_3OH + H_2O$
Methanol
Dissociation
$CH_3OH + H_2O$
$\rightarrow CO_2 + H_2$
Fuel Cell
H_2 or $CH_3OH \rightarrow$
Electricity
27
13, 21

FIG. 3